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Alternate Electron Donor Optimization Plan for ISB Operations at Test Area North Operable Unit 1-07B

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ABSTRACT

This Alternate Electron Donor Optimization Plan sets forth procedures, guidelines, and activities that will be carried out during the Alternate Electron Donor Optimization. Several electron donors, in addition to sodium lactate, were evaluated using various bench-scale tests and a cost analysis was performed to determine if an Alternate Electron Donor would be more cost-effective and/or efficient than sodium lactate for use during in situ bioremediation operations at Test Area North, Operable Unit 1-07B, at the Idaho National Engineering and Environmental Laboratory. Whey powder was recommended for Alternate Electron Donor optimization. The objective of this optimization is to evaluate if the use of whey for long-term operations will improve system performance and decrease the cost of in situ bioremediation at Test Area North Operable Unit 1-07B.

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ACRONYMS

AED	alternate electron donor
ARD	anaerobic reductive dechlorination
COD	chemical oxygen demand
DCE	dichloroethene
DNAPL	dense nonaqueous phase liquid
DQO	data quality objective
FY	fiscal year
IFT	interfacial tension
INEEL	Idaho National Engineering and Environmental Laboratory
ISB	in situ bioremediation
ORP	oxidation reduction potential
OU	operable unit
PCE	tetrachloroethene
QA	quality assurance
TAN	Test Area North
TCE	trichloroethene
TSF	Technical Support Facility
VC	vinyl chloride
VFA	volatile fatty acid
VOC	volatile organic compound

Alternate Electron Donor Optimization Plan for ISB Operations at Test Area North Operable Unit 1-07B

1. INTRODUCTION

In situ bioremediation (ISB) is part of the remedy selected for the contaminant groundwater plume at Test Area North (TAN) Operable Unit (OU) 1-07B at the Idaho National Engineering and Environmental Laboratory (INEEL). Currently, ISB involves regular injections of sodium lactate to stimulate bioremediation of chlorinated hydrocarbons in the contaminant source area of the groundwater plume. Operations are governed by the *In Situ Bioremediation Remedial Action Work Plan for Test Area North Final Groundwater Remediation, Operable Unit 1-07B* (DOE-ID 2003) and the *In Situ Bioremediation Operations and Maintenance Plan for Test Area North, Operable Unit 1-07B* (DOE-ID 2004). Part of the scope of operations under the ISB Remedial Action Work Plan is to evaluate alternatives to sodium lactate.

Several alternate electron donors (AEDs) have been evaluated in various laboratory tests to determine if an AED would be more effective than sodium lactate for use during ISB operations at TAN OU 1-07B. The results of the AED evaluation are presented in the draft "Fiscal Year 2003 Alternate Electron Donor Evaluation, Test Area North Final Remedy, Operable Unit 1-07B" (in preparation). As recommended by the evaluation, whey powder will be tested at TAN OU 1-07B. Whey powder was recommended because it enhances the dissolution of trichloroethene (TCE) in column studies more than sodium lactate, it had comparable dechlorination efficiency to sodium lactate, and it is less expensive than sodium lactate and the other AEDs evaluated. Based on these results, it was established that injection of whey powder instead of sodium lactate at TAN OU 1-07B could save several thousand dollars ($25K to $100K) annually.

This AED Optimization Plan sets forth procedures, guidelines, and activities that will be carried out to evaluate using whey powder as an alternative to sodium lactate. The data collected during the optimization will be used to make a performance comparison, based on cost and effectiveness, between whey powder and sodium lactate. This plan will also establish criteria for how the results will be interpreted in order to determine if replacement of sodium lactate with whey powder is desirable for long-term ISB operations at TAN OU 1-07B. All activities for the AED optimization will be governed by existing work controls and procedures found in the *In Situ Bioremediation Remedial Action Work Plan for Test Area North Final Groundwater Remediation, Operable Unit 1-07B* (DOE-ID 2003), the *In Situ Bioremediation Operations and Maintenance Plan for Test Area North, Operable Unit 1-07B* (DOE-ID 2004), and the *In Situ Bioremediation Remedial Action Groundwater Monitoring Plan for Test Area North, Operable Unit 1-07B* (INEEL 2003).

It is important to note that during the AED optimization, injections into TAN-1859 will cease in order to fully evaluate the results of whey injections into TSF-05. The utility of installing a packer in TAN-1859 will be evaluated to determine if this will improve distribution of the electron donor into the source area after the completion of the AED optimization. This improved distribution of electron donor could help meet compliance objectives at TAN OU 1-07B by decreasing flux of contaminants downgradient.

2. OBJECTIVES

The objective of the AED optimization is to evaluate if the use of whey powder for long-term operations will improve system performance and decrease the cost of ISB at TAN OU 1-07B. This evaluation will involve baseline monitoring of ISB following two injections of sodium lactate and groundwater monitoring following four injections of whey powder. The data needs and optimization process have been derived using the data quality objectives (DQO) process, as defined by the *Guidance for the Data Quality Objectives Process* (EPA 2000). This process was developed by the Environmental Protection Agency to ensure that the type, quantity, and quality of data used in decision-making are appropriate for the intended application. The process includes several steps, each of which has specific outputs that together form the DQOs for a given project. The results of each of the steps in the DQO process are outlined in Appendix A.

3. ALTERNATE ELECTRON DONOR OPTIMIZATION APPROACH

The five tasks of the AED optimization are discussed in this section. These tasks include

1. **Baseline Groundwater Monitoring during Sodium Lactate Injections** – Baseline groundwater sampling will occur following two sodium lactate injections prior to whey powder injections. Sample locations and frequency are identified in Section 3.1.

2. **Whey Powder Injection** – The initial whey powder injection will be equivalent to a 1X injection (12,000 gal) in TSF-05 with concentrations based on the laboratory studies. The injections are scheduled to occur four times; however, this number may increase or decrease depending on process decisions. This task is discussed in Section 3.2.

3. **Groundwater Monitoring during Whey Injections** – Groundwater sampling will occur following each whey injection. Sample locations and frequency will be similar to baseline monitoring and are identified in Section 3.3.

4. **Sample Analysis** – Groundwater samples taken during baseline monitoring and during whey powder injections will be analyzed for lactate, degradation products, chemical oxygen demand (COD), radionuclides, volatile organic compounds (VOCs), dissolved gasses, redox indicators, and microbial community parameters. Section 3.4 discusses this task.

5. **Data Interpretation and Reporting** – Data will be interpreted using methods described in Section 3.5. Results will be reported in forthcoming TAN OU 1-07B annual reports (see Section 7).

Procedures that will be used for these tasks are summarized in Table 3-1. All personnel will participate in a pre-job briefing before sample events. A schedule of the AED optimization is outlined in Section 5.

Table 3-1. Procedures/references used for alternate electron donor optimization tasks.

Task	Procedures
1. Sodium lactate injection	TPR-6899, "In Situ Bioremediation Facility Aqueous Electron Donor Injection"
2. Whey powder injection	TPR-6900, "In Situ Bioremediation Facility Solid Phase Electron Donor Injection"
3. Groundwater sampling	TPR-165, "Low-Flow Groundwater Sampling"; ISB Groundwater Monitoring Plan[a]; ISB Operations and Maintenance Plan[b]; TPR-6641, "New Pump and Treat Facility Purge Water Injection"
4. Sample analysis	TPR-166, "In Situ Bioremediation Field Laboratory Procedure"; TPR-6247, "Operable Unit 1-07B Troll 9000 Water Quality Probe Operation and Maintenance"; TPR-6248, "Operable Unit 1-07B Hydrolab Operation and Maintenance"
5. Data interpretation and reporting	AED Optimization Plan, ISB Remedial Action Work Plan[c]

a. *In Situ Bioremediation Remedial Action Groundwater Monitoring Plan for Test Area North, Operable Unit 1-07B* (INEEL 2003).

b. *In Situ Bioremediation Operations and Maintenance Plan for Test Area North, Operable Unit 1-07B* (DOE-ID 2004).

c. *In Situ Bioremediation Remedial Action Work Plan for Test Area North Final Groundwater Remediation, Operable Unit 1-07B* (DOE-ID 2003).

TPR = technical procedure.

3.1 Task 1 – Baseline Groundwater Monitoring

Currently, as part of ISB operations, monthly groundwater monitoring data are collected from TSF-05A, TSF-05B, TAN-25, TAN-26, and TAN-31 approximately 1 and 5 weeks following sodium lactate injections. These data will be used for making recommendations and process decisions during the AED optimization, along with additional data collected specifically for the AED optimization at these same locations. Figure 3-1 illustrates a hypothetical data set from groundwater monitoring of TCE in TSF-05A. As is demonstrated, the data available from regular ISB sampling show an initial increase in TCE concentration in response to sodium lactate injections, as measured at Week 1, followed by a subsequent reduction in TCE concentration to near the detection limit, as measured at Week 5. However, based on the AED evaluation results, significant changes in TCE concentration may occur during and immediately after injection. The current ISB monitoring program is insufficient to observe these types of changes following sodium lactate injections in the field. Therefore, additional sampling is needed to provide resolution to more accurately quantify enhanced TCE dissolution from the residual source. As described in Section 3.3, this same high-resolution monitoring will also be conducted following whey powder injections such that relative comparisons between the enhanced dissolution observed following lactate and whey injections can be made.

The baseline data will come from samples collected after the last two 1X 6% sodium lactate injections into TSF-05 prior to AED injections and will include the following analytes collected at TSF-05A, TSF-05B, TAN-25, and TAN-31:

- VOCs (TCE, tetrachloroethene [PCE], cis/trans-DCE, and vinyl chloride [VC])
- Ethane/ethene/methane

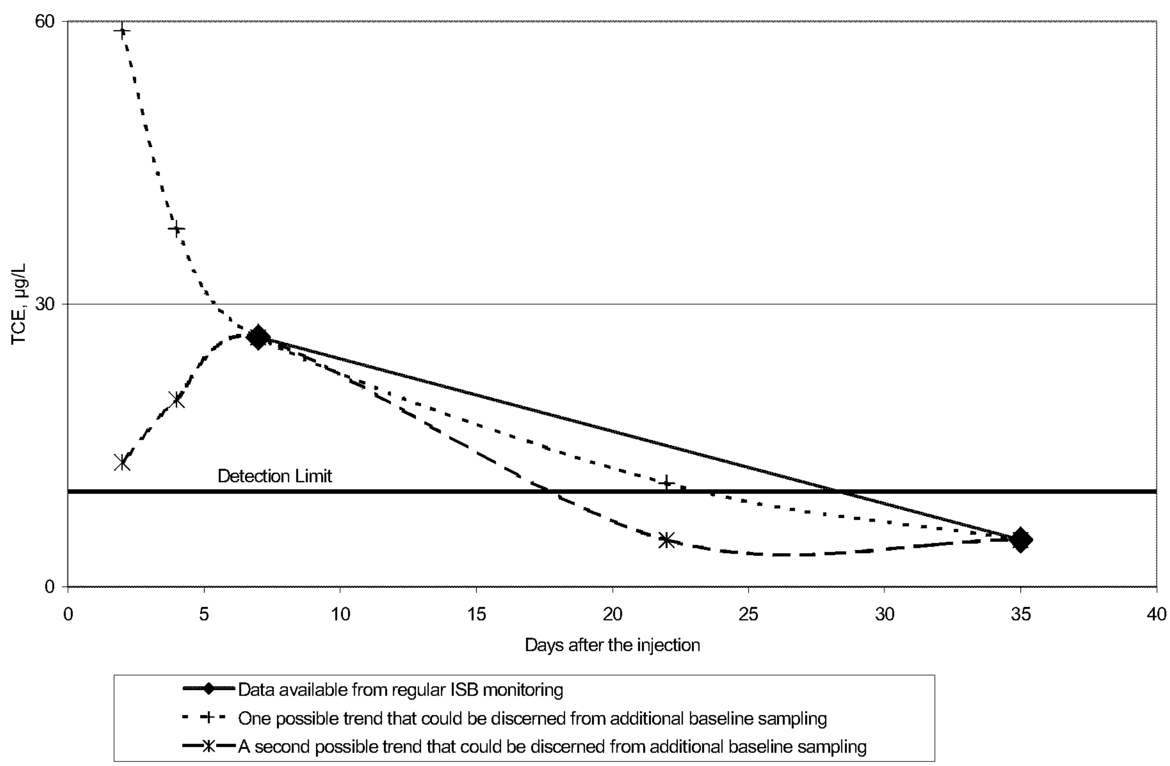

Figure 3-1. Hypothetical data set from groundwater monitoring of TCE in TSF-05A.

- COD
- Propionate, butyrate, acetate, lactate, and other volatile fatty acids (VFAs)
- Sr-90 (collected only during monthly ISB sampling)
- Tritium (collected only during monthly ISB sampling)
- Gamma screen (collected only during monthly ISB sampling)
- Microbiological (collected at TAN-25 only).

For scheduling purposes, the day of the electron donor injection will be considered Day 1 with baseline samples being collected on Day 2, Day 4, Days 8 through 11 (monthly ISB sampling), approximately Day 22, and Days 36 through 39 (monthly ISB sampling) (see Section 5). It is important to note that microbiological samples will be collected at TAN-25 only. In addition, Sr-90, tritium, and gamma screen samples, along with all samples collected at TAN-26 (this also includes Sr-90 and tritium), will only be collected during monthly ISB sampling.

Besides being used to compare enhanced dissolution effects, this baseline data will allow microbial community shifts, acclimation rates, utilization rates, dechlorination rates, and process decisions to be determined in order to compare whey powder with sodium lactate. ISB sampling and analyses, and the additional groundwater sampling and analyses necessary for the AED optimization, are governed by and permitted under the ISB Groundwater Monitoring Plan (INEEL 2003). Refer to the ISB Groundwater Monitoring Plan for the procedures and requirements for groundwater sampling and analyses.

3.2 Task 2 – Whey Powder Injection

Sodium lactate has been injected in TSF-05 since 1999 (INEEL 2000). Various concentrations and injection strategies have been implemented during the Field Evaluation, Pre-design, and Interim Operations phases. The most recent and frequent injections have been approximately 12,000 gal of 6% sodium lactate (1X, 6%). These injections begin with the injection of sodium lactate solution, followed by a potable water flush. Under the current injection strategy, injections occur every 8 weeks in both TSF-05 and TAN-1859.

Initially, whey will be injected using a 10% solution (w/w) and a total of 12,000 gal. The injection rate will be approximately 40 gallons per minute (gpm) of whey solution. The injection will be followed by a 1-hour potable water flush (approximately 2,000 gal). Whey powder injections are planned to occur every 8 weeks. Although injections will initially follow this strategy, they may be modified if groundwater monitoring indicates that distribution, concentration, or utilization data will not be comparable to that observed during sodium lactate injections. During the AED optimization, injections into TAN-1859 will cease in order to eliminate any interference that may occur by continuing to inject sodium lactate into this well.

3.3 Task 3 – Groundwater Monitoring During Whey Injections

Similar to the baseline groundwater sampling, additional data will come from groundwater monitoring samples collected after whey powder injections into TSF-05. These will include the same procedures, analytes, frequency, and monitoring wells as outlined in Section 3.1, with the exception that Sr-90 will only be monitored in TAN-25 during monthly ISB sampling.

3.4 Task 4 – Sample Analysis

Analyses of pH, sulfate, iron, and COD will be performed in the ISB field laboratory. All field analyses will be performed per TPR-166, "In Situ Bioremediation Field Laboratory Procedure." The oxidation reduction potential (ORP) will be collected using an in situ multi-parameter water quality instrument at TAN-31. VOCs, dissolved gases, lactate, acetate, propionate, butyrate, and other VFA analyses will be conducted at the INEEL Research Center. Microbial analyses will be performed at Idaho State University. Tritium and Sr-90 will be shipped off-Site for analyses following the same procedures used to ship samples off-Site for monthly ISB sampling. All sample management and analysis will follow the protocols in the ISB Groundwater Monitoring Plan (INEEL 2003).

3.5 Task 5 – Data Interpretation and Reporting

Data from groundwater monitoring will be used to make the final recommendation and process decisions. The decision inputs are results of sample collection, calculated parameters, and/or observations that represent conditions such as dechlorination, utilization of AED, dissolution of TCE from the source, radionuclide concentration increase, microbial community health, AED distribution, and cost. The following sections provide a description of each of these parameters and provide some detail on methods for calculating and comparing them.

3.5.1 Dechlorination

Results from AED evaluations show that whey powder stimulates anaerobic reductive dechlorination (ARD) of TCE at least as effectively as sodium lactate in microcosms, but this dechlorination must be evaluated at the field scale to confirm that this same result will happen in the field. Dechlorination will be evaluated considering TCE concentration trends, redox parameters, and contaminant ratios.

3.5.1.1 TCE Trends. Past observations suggest that dissolution of TCE from the source is a factor controlling the bioavailability of TCE to dechlorinating bacteria in the portion of the source area impacted by electron donor. Increases in TCE concentrations following injection of AED may be observed due to enhanced dissolution from the source. If enhanced source dissolution is observed, then dechlorination will need to proceed at a rate sufficient to prevent accumulation of TCE and daughter products in the source area. Therefore, observed increases in TCE concentrations immediately following a whey powder injection must be followed by a decrease in TCE concentration and an increase in ethene concentration.

3.5.1.2 Methane, Sulfate, and Dissolved Oxygen. Complete ARD of TCE is dependent upon redox conditions and the health of the microbial community (see Section 3.5.5). Field observations at TAN have shown that ARD begins when redox conditions are sulfate-reducing, but complete dechlorination is most effective under methanogenic conditions. Sodium lactate injections result in utilization and depletion of available electron acceptors such as oxygen, nitrate, sulfate, and ferric iron. This depletion is caused by the reduction of the electron acceptor that is present in the surrounding aquifer. As more energetically favorable electron acceptors are used, anaerobic degradation becomes more prevalent. ARD of TCE only becomes energetically favorable under methanogenic conditions. A correlation between methane and ethene production was observed at TAN in that observations of methane production corresponded to more efficient ARD (INEEL 2000). Continued absence of sulfate and production of methane will be used as indicators that injections of whey powder have maintained redox conditions sufficient for ARD. In addition, chlorinated ethene, microbiological, and redox parameter trends will be plotted and updated periodically throughout the optimization study. These graphical presentations and calculation of parameters from the concentration data will provide a basis for observing dechlorination trends.

3.5.1.3 Contaminant Ratios and Chlorine Number. Dechlorination extent can be determined by observing trends in ARD daughter products. The chlorine number and contaminant ratios may be used to represent the relative dechlorination state of chlorinated and nonchlorinated ethenes. The chlorine number can only be used in conjunction with supporting data because trans-DCE has been observed to be recalcitrant, thus making direct interpretation of chlorine number as a measure of dechlorination extent unreliable. In addition to contaminant ratios and chlorine number, dechlorination extent can be observed by production of ethene. Observations of ethene production following AED injection and TCE reduction may be used to confirm complete dechlorination. Dechlorination can stall if the proper microbial community is not present or not stimulated. This stall can be observed by an increase in DCE concentration. The concentrations of cis- and trans-DCE will be monitored for this purpose. If source dissolution occurs and rapid ARD follows, then an increase in DCE concentrations may be observed, but VC and ethene production should follow.

3.5.2 Utilization of Alternate Electron Donor

The AED evaluation assessed utilization of electron donors based on calculation of first-order degradation rates. The utilization of electron donor was correlated to TCE degradation rates by calculating the total amount of ethene generated per unit COD used. For application in the field, the degradation or utilization rate calculated for whey is related to the longevity of the electron donor, which ultimately will dictate the frequency of injections required. The AED evaluation results suggest that whey will be utilized at a faster rate than sodium lactate, as described in the "Fiscal Year (FY) 2003 AED Evaluation Report" (in preparation). This will be tested during the optimization. The effectiveness or necessary injection frequency will be determined based on length of time COD remains present in the system to stimulate conditions conducive to dechlorination. In addition to COD degradation rate, production of organic acids (i.e., acetate, propionate, and butyrate) will also be determined.

3.5.3 Dissolution of TCE from the Source

Interfacial tension (IFT) analyses and column studies were performed during the AED evaluation to determine the effect of an AED solution on TCE dense nonaqueous phase liquid (DNAPL). The evaluation results suggest that whey injections may significantly enhance dissolution of TCE from the residual source DNAPL at TAN. Baseline monitoring of TCE concentration trends on Day 2, Day 4, Days 8 through 11, approximately Day 22, and Days 36 through 39 after injections are intended to resolve the magnitude of the TCE spike observed after sodium lactate injections. These concentration spikes may be the result of dissolution from the residual source. This monitoring strategy will continue during injections of AED in order to compare the magnitude of the TCE concentration increase immediately following injection. As discussed in Section 3.5.1, if the increased concentration of TCE is then observed to decrease coincident with daughter product increases, the observation will be attributed to dechlorination. In this way, an estimate of TCE mass removed due to enhanced dissolution and subsequent dechlorination will be possible. The rate of dechlorination can be compared to that observed following sodium lactate injections during the baseline sampling. These data can then be used to estimate the effect whey powder will have on decreasing remedial time relative to sodium lactate.

Several parameters will be evaluated during the AED optimization as confirmation of enhanced dissolution. During the TAN enhanced ISB pilot study comparing concentrations of TCE to concentrations of tritium, a co-contaminant within the residual source area confirmed that TCE concentration increases are a result of enhanced dissolution (DOE-ID 2000). Tritium is not expected to be affected by enhanced dissolution properties; however, concentrations of tritium have decreased as a result of radioactive decay and may be difficult to include in the analyses. One potential downfall of significantly enhancing the dissolution of TCE is that accumulation of TCE and/or daughter products may be significant if dechlorination rates are not sufficient to degrade the contaminants. For purposes of the pilot study, ethene production may also be observed as confirmation that enhanced dissolution has resulted in ARD of more TCE. If this does not occur, whey cannot be recommended for replacement of sodium lactate; and, if the newly mobilized TCE concentrations are excessive, consideration must be given to stopping whey injections.

3.5.4 Radionuclide Concentration Increase

Contaminants of concern in the residual source area include both VOCs and radionuclides. Enhanced dissolution effects on the residual source area for TCE may also affect the release of Sr-90. Although Sr-90 is present in the source area, it does not migrate outside of the source area due to sorption and co-precipitation with calcite. Therefore, release of Sr-90 is not expected to be a concern. However, to ensure that this is the case during whey powder injections, Sr-90 concentrations will be monitored throughout the optimization. If the radionuclide concentrations during whey powder injections are significantly higher (i.e., >50%) than the concentrations observed during baseline sampling, migration of Sr-90 from the source zone will be evaluated. The whey powder injections will be stopped if it is determined that Sr-90 is or might in the future escape from the source zone.

3.5.5 Microbial Community Health

Complete ARD of TCE is dependent upon redox conditions (see Section 3.5.1) and the health of the microbial community. To assess the health of the microbial community, analyses of 16s ribosomal DNA will be evaluated to compare microbial communities induced with sodium lactate and whey. Sampling frequency is expected to be sufficient to observe microbial community shifts that coincide with AED injection, AED utilization, and dechlorination. These trends will be observed for sodium lactate injections during baseline sampling and then compared to trends following whey powder injections. Terminal restriction fragment length polymorphism, polymerase chain reaction, and data interpretation will be similar to that performed for samples taken from microcosm studies during the FY 2003 AED Evaluation (in preparation).

3.5.6 Alternate Electron Donor Distribution

Column studies conducted during the AED evaluation showed that all AEDs were transported efficiently through columns packed with basalt. The IFT properties were preserved after transport across this matrix. It is suspected that whey powder will be distributed through the aquifer in a manner similar to sodium lactate at higher concentrations. A 10% whey solution (specific gravity of 1.04) is less dense than a 6% solution of sodium lactate (specific gravity of 1.05); therefore, density-driven transport at concentrations less than or similar to this is not expected to be a problem. This will be tested during whey powder injections by monitoring COD and degradation product concentrations in TSF-05A, TSF-05B, TAN-25, TAN-31, and TAN-26. COD data from monthly ISB sampling in TAN-1859 and other wells may also be used in evaluating the extent of AED distribution.

3.5.7 Cost

Cost will be evaluated by comparing the cost of injection for sodium lactate to whey powder injection and by evaluating the cost considering ARD efficiency and electron donor utilization. The cost of an injection is summarized in Section 6. This budget will be revised according to actual costs recorded during the optimization. The revised budget will then be used to create a cost-benefit analysis for the scale-up, taking into consideration the lifetime operation cost of any additional equipment necessary for injection of whey powder. Cost will also be assessed considering the savings resulting from decreased remediation time relative to sodium lactate.

4. ENVIRONMENT, SAFETY, HEALTH, QUALITY, AND WASTE MANAGEMENT

4.1 Environment, Safety, and Health

The *Test Area North Operable Unit 1-07B Final Groundwater Remedial Action Health and Safety Plan* (INEEL 2002a) establishes procedures and requirements that are used for all activities associated with OU 1-07B. The personnel responsible for AED optimization sampling activities are presented in Table 4-1.

4.2 Quality Assurance

Samples will be collected and analyzed in accordance with the *Quality Assurance Project Plan for Waste Area Groups 1, 2, 3, 4, 5, 6, 7, 10, and Inactive Sites* (DOE-ID 2002).

Minimum external and internal quality assurance (QA) frequencies and corrective actions will be the same as those used for ISB groundwater monitoring, as specified in the ISB Groundwater Monitoring Plan (INEEL 2003) and TPR-166. Corrective actions will be performed when the precision and accuracy ranges specified in these documents are exceeded.

4.3 Waste Management

All waste managed during the AED optimization period will be managed in accordance with the provisions of the *Waste Management Plan for Test Area North Final Groundwater Remediation, OU 1-07B* (INEEL 2002b). Sampling activities described in Section 3 will generate listed waste (i.e., contaminated wipes, sample bottles, personal protective equipment, and purge water). All of the solid materials will be bagged and labeled with the contents (e.g., waste code F001 for TCE). The waste will be transferred to a storage area under the direction of Waste Generator Services personnel. Unaltered purge water will be transferred to the New Pump and Treat Facility for processing. Sample residue from field analysis will be managed in accordance with the OU 1-07B Waste Management Plan.

Table 4-1. Alternate electron donor optimization personnel roles and responsibilities.

Functional Role	Responsibilities
OU 1-07B ISB technical lead	Overall ISB technical direction
Optimization supervisor	Supervise AED optimization; provide direction to the FTL and FLL
FTL	Implement field sampling; coordinate activities
FLL	Direct field lab operations
Field engineer	Perform injections, treat purge water, develop and implement work controls and safety
FTM	Perform sampling, analysis, recording, and other tasks as directed by the FTL and FLL

FLL = field lab lead.
FTL = field team leader.
FTM = field team members.

5. SCHEDULE

Figure 5-1 identifies the schedule for baseline groundwater monitoring, four AED injections, and subsequent AED sampling associated with the AED optimization. Appendix B contains tables showing the detailed schedule and the analyte sets for the optimization. Based on data analysis and process decisions, the optimization may be extended by adding injections and sample events but will last no longer than 18 months. In addition, the optimization may be terminated at any time based upon the determination that sufficient data have been obtained.

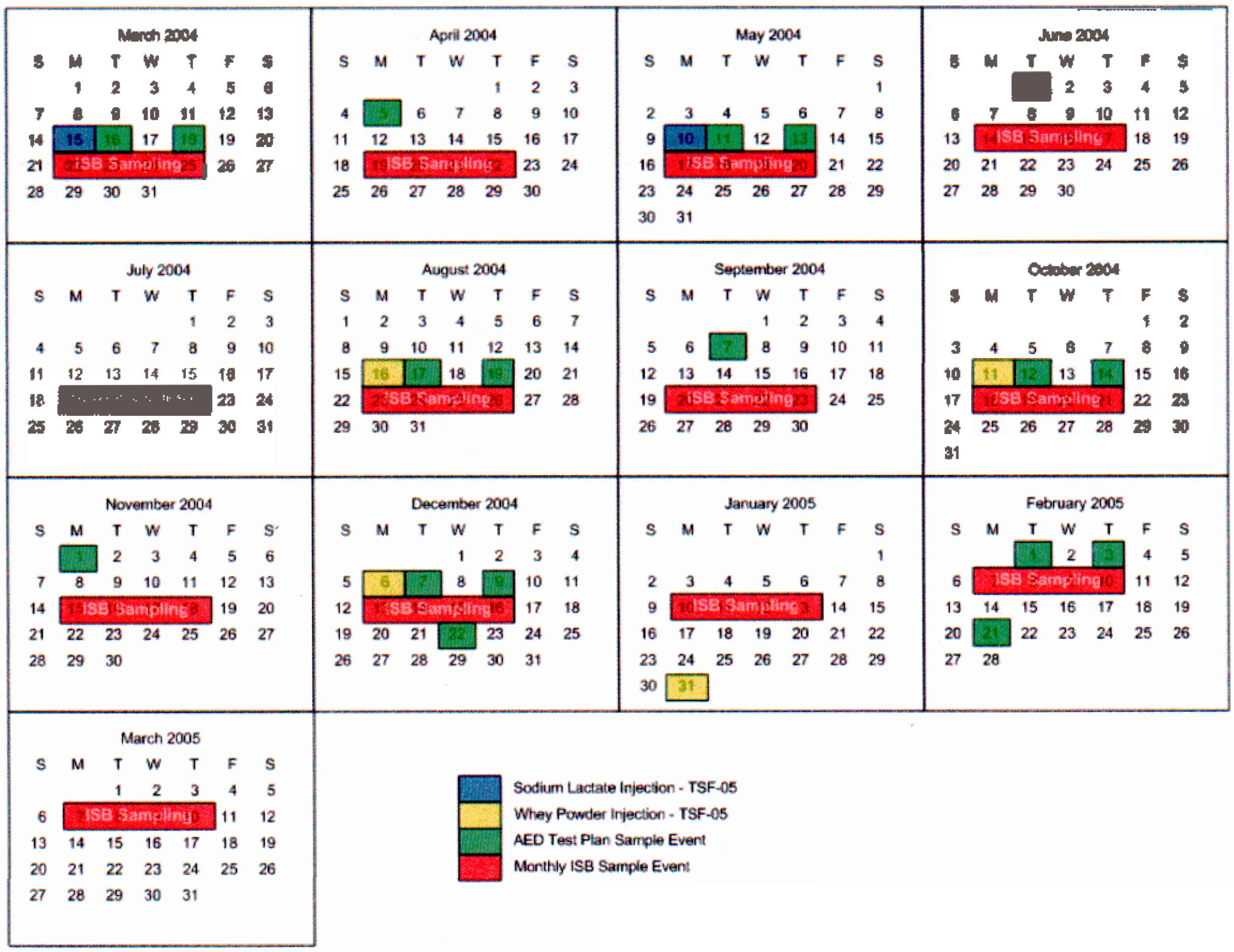

Figure 5-1. Injection and sampling schedule.

6. BUDGET

The cost estimate for performing the AED optimization is presented in Table 6-1. The costs included in this budget are for the two baseline sampling events, four whey powder injections, any sampling and analysis in addition to the already scheduled ISB monthly sampling and analysis, and data interpretation and report preparation. Since sodium lactate injections will be discontinued during the AED optimization, a significant cost savings will result. These cost savings have been estimated and are presented in Table 6-2. This cost savings estimate is based on the injection schedule for both TSF-05 and TAN-1859 (injections every 8 weeks) during normal initial operations. Based on this schedule, six sodium lactate injections would have to be performed into both TSF-05 and TAN-1859 (for a total of 12 separate injections) over the same period as the AED optimization. Since the AED optimization includes six injections (two baseline sodium lactate and four whey powder injections), a labor cost savings for six injections is shown. Another cost savings is shown for the material cost of sodium lactate that would have been injected into TSF-05 and TAN-1859 over the AED optimization period. This cost savings is based on the total of 12 injections planned for interim operations minus the two sodium lactate baseline injections. It is important to note that cost savings may decrease if the optimization is terminated before the four injections have been made, or the cost savings may increase if it is determined that more frequent injections are necessary.

Table 6-1. Alternate electron donor optimization cost estimate.

Activity	FTEs	Resource	Hours per FTE	Total Cost ($)	Comments
Baseline and groundwater sampling	2	FTM	180	18,000	Sample and preserve COD and Sr-90
	1	FTL	180	10,800	—
	1	Field engineer	60	3,600	Process purge water
Data analysis and interpretation	1	Env. engineer	80	5,200	—
Technical oversight	1	Project manager	40	3,600	—
Report preparation	1	Env. engineer	120	7,800	—
Activity		**Analysis**	**Quantity**	**Total Cost ($)**	**Comments**
Sample Analysis		VOCs	72	2,400	—
		EEM	72	2,400	—
		PBAL and AED	72	2,400	—
		COD	72	550	—
		Sr-90	27	5,037	—
		Tritium	0	0	—
		Gamma screen	0	0	—
		Microbiological	51	35,200	—

Table 6-1. (continued).

Activity	Materials	Quantity	Total Cost ($)	Comments
AED injection	Whey powder	4	11,616	—
Sampling materials	Bottles and PPE	NA	2,000	—
Total			$110,603	—

AED = alternate electron donor.

COD = chemical oxygen demand.

EEM = ethane/ethene/methane.

FTE = full-time employee.

FTL = field team leader.

FTM = field team member.

NA = not applicable.

PBAL = propionate, butyrate, acetate, lactate.

PPE = personal protective equipment.

VOCs = volatile organic compounds.

Table 6-2. Alternate electron donor optimization cost savings estimate.

Activity	FTEs	Resource	Hours per FTE	Total Cost Saving ($)	Comments
Curtailment of sodium lactate injections	1	Field engineer	150	9,750	Saved labor costs due to curtailment of six injections
Activity		**Materials**	**Quantity**	**Total Cost Saving ($)**	**Comments**
Curtailment of sodium lactate injections		Sodium lactate	10	115,632	Cost savings from curtailment of injections into TAN-1859 and TSF-05
Total				$125,382	

FTE = full-time employee.

7. REPORTING

All data collected, data interpretation, and the final recommendation regarding the continued use of whey powder in the place of sodium lactate will be reported in future TAN OU 1-07B ISB annual reports.

8. REFERENCES

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Appendix A

Data Quality Objectives

Appendix A

Data Quality Objectives

The seven steps of the DQO process are discussed in this appendix.

A-1 Problem Statement

The first step in the DQO process is simply to state the problem to be addressed and to put it in its programmatic context. The AED optimization will evaluate if whey powder can replace sodium lactate as an amendment for enhanced ISB, as suggested in the OU 1-07B FY 2003 AED Evaluation (in preparation). Performance and cost parameters will be evaluated relative to the current amendment, sodium lactate, and the output is a recommended electron donor for long-term ISB operations.

A-2 Decision Identification

The decision identification step in the DQO process is used to identify the decisions and the potential actions that will be affected by the data collected. Groundwater monitoring data will be used to evaluate the effectiveness of the AEDs and form a recommendation regarding the replacement of sodium lactate with whey powder for long-term ISB operations. Additionally, throughout the optimization, process modifications may be necessary to achieve the objectives. Three process decisions are possible:

- **Process Decision 1.** Modify the injection. Injection modifications may include changes to injection duration, volume, concentration, or frequency.

- **Process Decision 2.** Modify the sampling. Modifications to the sampling may include changing the frequency of sampling or the addition of analytes in certain wells. Modifications to sampling will not include decreasing the frequency of monthly ISB sampling as required by the ISB Remedial Action Work Plan (DOE-ID 2003).

- **Process Decision 3.** Stop the optimization. This decision includes stopping whey injections, completing interpretation of groundwater monitoring data, and making the recommendation.

A-3 Decision Inputs

Decision inputs are the parameters required to help make the process decisions identified in the previous section. These inputs will allow observations to be made describing the effects that whey has on key parameters such as dechlorination, dissolution of radionuclides from the source area, and aquifer conditions. The data used for decision inputs will come from monthly ISB sampling as required by the ISB Remedial Action Work Plan (DOE-ID 2003) and from additional groundwater monitoring of TAN-31, TSF-05A, TSF-05B, TAN-25, and TAN-26 defined in this Work Plan. Inputs used to make a recommendation regarding whey will be assessed relative to similar data obtained following sodium lactate injections. In addition, process decision inputs will be evaluated after each sampling round. It is important to note that much of this sampling will be completed as part of regular ISB operations, and all sampling, including any additional analytes, will be governed by the ISB Groundwater Monitoring Plan (INEEL 2003).

Table A-1 is a summary of analytical data that will be used to form decision inputs. Guidelines detailing how these decision inputs will be calculated, quantified, and compared are included in

Table A-1. Groundwater monitoring data used to form decision inputs.

Group	Analyte	Decision Inputs: Recommendation	Decision Inputs: Process Decisions	Wells
Lactate and electron donor degradation products	Lactate	Utilization and cost	Distribution and utilization	TAN-31, TAN-25, TSF-05A, and TSF-05B
	Acetate	Utilization	Utilization	TAN-31, TAN-25, TSF-05A, and TSF-05B
	Propionate	Utilization	Utilization	TAN-31, TAN-25, TSF-05A, and TSF-05B
	Butyrate	Utilization	Utilization	TAN-31, TAN-25, TSF-05A, and TSF-05B
Chemical oxygen demand	COD	Utilization	Distribution and utilization	TAN-31, TAN-25, TSF-05A, and TSF-05B
Radionuclides	Tritium	Dissolution	Dissolution	TAN-31, TAN-25, TSF-05A, and TSF-05B
	Sr-90	Radionuclide concentration	Radionuclide concentration	TAN-25 and TAN-26
Dissolved gases	Ethene	Dechlorination	Dechlorination	TAN-31, TAN-25, TSF-05A, and TSF-05B
	Ethane	Dechlorination	Dechlorination	TAN-31, TAN-25, TSF-05A, and TSF-05B
	Methane	Dechlorination	Dechlorination	TAN-31, TAN-25, TSF-05A, and TSF-05B
VOCs	PCE	Dechlorination	Dechlorination	TAN-31, TAN-25, TSF-05A, and TSF-05B
	TCE	Dechlorination and dissolution	Dechlorination and dissolution	TAN-31, TAN-25, TSF-05A, and TSF-05B
	cis-DCE	Dechlorination	Dechlorination	TAN-31, TAN-25, TSF-05A, and TSF-05B
	trans-DCE	Dechlorination	Dechlorination	TAN-31, TAN-25, TSF-05A, and TSF-05B
	VC	Dechlorination	Dechlorination	TAN-31, TAN-25, TSF-05A, and TSF-05B
Microbial parameters	DNA	Microbial community health		TAN-25
Redox indicators	Sulfate	Dechlorination	Dechlorination	TAN-31, TAN-25, TSF-05A, and TSF-05B
	Iron	Dechlorination	Dechlorination	TAN-31, TAN-25, TSF-05A, and TSF-05B
	pH	Dechlorination	Dechlorination	TAN-31, TAN-25, TSF-05A, and TSF-05B
	ORP	Dechlorination	Dechlorination	TAN-31

COD = chemical oxygen demand.
DNA = deoxyribonucleic acid.
ORP = oxidation reduction potential.
PCE = tetrachloroethene.
TCE = trichloroethene.
VC = vinyl chloride.

Section 3.3 of the report. The decision inputs for AED recommendation and process decisions will be evaluated from the groundwater monitoring data (Table A-1). The decision inputs are comparative evaluations of parameters that are pertinent to electron donor effectiveness and cost. These parameters include

- Dechlorination
- Utilization of AED
- Dissolution of TCE from the source
- Radionuclide concentration increase
- Microbial community health
- AED distribution
- Cost.

A-4 Boundaries

This step in the DQO process defines the boundaries of the study to clarify the sample domain. These boundaries include spatial and temporal boundaries, both of which are described below.

A-4.1 Spatial Boundaries

The spatial boundaries simply define the physical extent of the study area and may be subdivided into specific areas of interest. The spatial boundaries are defined by the wells to be sampled for the AED optimization. These wells include TSF-05A, TSF-05B, TAN-25, and TAN-31. TAN-26 will also be sampled to confirm that whey powder does not reach the screened interval of TAN-26. Monthly groundwater monitoring will also occur as part of ISB operations in the wells mentioned and in other wells as required by the ISB Remedial Action Work Plan (DOE-ID 2003). Data from this regular ISB groundwater monitoring may also be used as needed in evaluating decision inputs.

A-4.2 Temporal Boundaries

The temporal boundaries define the duration of the study or specific parts of the study. The temporal boundaries of this optimization are defined by the duration of the optimization, as outlined by the schedule in Section 5. It has been estimated that four injections of whey will be necessary to ensure sufficient data collection; however, the temporal duration will be determined by process decisions. These decisions may stop the optimization early or prolong it. The decision to stop the optimization will be made if, at any time, it is determined that injection of whey powder has or will have an adverse effect on ISB operations. In the event that additional injections are needed to obtain sufficient data, it is expected that the optimization duration will be no longer than 18 months.

A-5 Decision Rule

The objective of this step is to develop a logical statement that defines the conditions that would cause the decision-maker to choose among alternative actions. For the AED optimization, two types of decisions have been identified: a recommendation decision and three process decisions. The decision rules for each type of decision are presented below.

A-5.1 Recommendation Decision

The decision to recommend that whey replace sodium lactate as the electron donor at TAN OU 1-07B will be determined by the effectiveness and cost of whey powder. Effectiveness of whey powder will be based on how well it stimulates dechlorination and promotes dissolution of TCE from the source. Effectiveness of whey powder will also be based upon the rate it is utilized, increases in radionuclide concentrations (if any), and the health of the microbial community. Effectiveness of whey powder on ISB will be determined independent of cost. Cost will be evaluated considering the cost per injection and the frequency of injections necessary. Other cost parameters may be calculated in order to consider the impacts that whey may have on the remedial timeframe relative to sodium lactate. The methods for calculating the parameters that will determine effectiveness and cost are summarized in Section 3.5. If there is an observed adverse effect on the ISB system, then whey powder will not be recommended regardless of cost or effectiveness. This adverse effect may be an uncontrolled increase in radionuclide concentration or an increase in TCE concentration and VOC degradation products in the source area. Neither scenario is expected, but each will be monitored. The recommendation decision rule is summarized in Table A-2.

A-5.2 Process Decisions

The process decision to modify the injection will be made if AED distribution is insufficient, if density-driven transport is evident, or if utilization rates suggest that injection frequency and/or concentration need to be modified. Insufficient distribution of whey will be evident if AED daughter products or COD are not detected in TAN-31 and/or TAN-25 following the first injection. If insufficient distribution occurs, a likely solution will be to increase the volume of the injection. If COD is detected in significant quantities in TAN-26, then density-driven transport of the whey to the lower largely uncontaminated portion of the aquifer is possibly occurring. A likely solution to density effects will be to decrease whey concentration in the injection. Utilization rates may suggest that injection strategies need to be changed as well, which may entail increasing or decreasing the frequency of injections or whey concentration in the injection.

Table A-2. Decision matrix for the recommendation decision.

Cost (More than/less than/same as sodium lactate)	Effectiveness (More than/less than/same as sodium lactate)	Decision (Recommend AED = Yes Not recommend AED = No)
More	More	Decision will be based on data
More	Less	No
Less	More	Yes
Less	Less	No
Same	More	Yes
Same	Less	No
More	Same	No
Less	Same	Yes
Same	Same	No

The process decision to modify the sampling will be made if it is determined that data obtained will be insufficient to support the recommendation or process decisions. A decision to modify the sampling will be made if data for any one of the analytes mentioned in Table A-1 are determined to be of insufficient quantity or quality to calculate decision inputs within reasonable error limits. Another modification may be to increase the number of sampling events between injections or to add analytes. The decision will also be made to modify the sampling if analyses in TAN-26 and TAN-31 suggest AED distribution beyond the spatial boundaries of the study has occurred. In this case, data from TAN-D2 or TAN-1859 may be necessary to fully evaluate these effects. The modification in this case will be to add the data already regularly collected from TAN-D2 or TAN-1859 to the suite of data considered in supporting optimization decisions. An additional modification may be to decrease the number of samples taken or the number of analytes if it is determined that the data are not necessary to meet the objectives.

The process decision to stop the optimization will be made if it is determined that sufficient data have been obtained or if an adverse effect is observed. The number of whey injections and the duration are discussed in Section 3.2 and Section 5, respectively. Both of these are dependent on a process decision to stop the optimization. At least four whey injections are planned in order to obtain sufficient data to make the recommendation. However, the decision to stop the optimization will be made when sufficient data are obtained to meet the objective to evaluate if the use of the AED for long-term operations will improve system performance and decrease the cost of ISB at TAN OU 1-07B. An observed adverse effect on ISB will automatically require a decision to stop the optimization. An adverse effect could be a substantial increase (i.e., > 50%) in Sr-90 concentrations that appears to be migrating from the source area or a rapid increase in TCE concentration that does not decrease to low concentrations before the next injection (at least comparable to the concentration decrease observed following sodium lactate injections).

A-6 Decision Error Limits

Decision error limits for data, validation levels, and performance goals for uncertainty will be the same as those outlined in the ISB Groundwater Monitoring Plan (INEEL 2003). Data that meet this quality level will be used to calculate parameters that will be used for decision inputs.

A-7 Design Optimization

The purpose of design optimization in the DQO process is to identify the best design that has resulted. The results of this DQO process suggest that an iterative process is necessary in which injections, groundwater monitoring, and data interpretation methods may be modified based on initial results. The optimization will proceed until sufficient data have been collected to make a recommendation to use whey or continue to use sodium lactate. This iterative process will be carried out according to certain process decisions described in Section A-2 of this appendix. These process decisions may be made at any time during the optimization. It is anticipated that this process will require at least four injections of whey powder along with the sampling and analyses that will follow each injection. Table A-1 has been presented as a list of analytes and wells that will be used in the AED optimization. The sampling schedule and strategy presented in this report have resulted from the DQO process documented in this appendix.

Appendix B

Schedule and Analytes

Table B-1. AED optimization schedule.

Date(s)	Activity (Day)	Location (Analyte Set[a])
March 15, 2004	Sodium lactate injection 1X 6% (Day 1)	TSF-05 (NA)
March 16, 2004	Baseline groundwater monitoring (Day 2)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
March 18, 2004	Baseline groundwater monitoring (Day 4)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
March 22-25, 2004	ISB sampling, monthly (Days 8-11)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{90}Sr, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
Apr. 5, 2004	Baseline groundwater monitoring (Day 22)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
Apr. 19-22, 2004	ISB sampling, monthly (Days 36-39)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{90}Sr, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
May 10, 2004	Sodium lactate injection 1X 6% (Day 1)	TSF-05 (NA)
May 11, 2004	Baseline groundwater monitoring (Day 2)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
May 13, 2004	Baseline groundwater monitoring (Day 4)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
May 17-20, 2004	ISB sampling, semiannual (Days 7-10)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{90}Sr, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
June 1, 2004	Baseline groundwater monitoring (Day 23)[b]	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
June 14-17, 2004	ISB sampling, monthly (Days 36-39)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{90}Sr, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
July 19-22, 2004	ISB sampling, monthly NPTF performance (Days 70-73)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
Aug. 16, 2004	Whey injection #1 (Day 1)	TSF-05 (NA)

Table B-1. (continued).

Date(s)	Activity (Day)	Location (Analyte Set[a])
Aug. 17, 2004	Groundwater monitoring (Day 2)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
Aug. 19, 2004	Groundwater monitoring (Day 4)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
Aug. 23-26, 2004	ISB sampling, quarterly (Days 8-11)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
Sept. 7, 2004	Groundwater monitoring (Day 23)[c]	TSF-05A, TSF-05B, TAN-31 26 (AED Analysis Set) TAN-25 26 (AED Analysis Set, MP)
Sept. 20-23, 2004	ISB sampling, monthly (Days 36-39)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
Sept. 20-Oct. 10, 2004[d]	Analyze current data/ process decision	NA
Oct. 11, 2004	Whey injection #2 (Day 1)	TSF-05 (NA)
Oct. 12, 2004	Groundwater monitoring (Day 2)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
Oct. 14, 2004	Groundwater monitoring (Day 4)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
Oct. 18-21, 2004	ISB sampling, monthly (Day 8-11)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
Nov. 1, 2004	Groundwater monitoring (Day 22)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
Nov. 15-18, 2004	ISB sampling, annual (Days 36-39)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
Nov. 22-Dec.3, 2004[d]	Analyze current data/ process decision	NA
Dec. 6, 2004	Whey injection #3 (Day 1)	TSF-05 (NA)
Dec. 7, 2004	Groundwater monitoring (Day 2)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)

Table B-1. (continued).

Date(s)	Activity (Day)	Location (Analyte Set[a])
Dec. 9, 2004	Groundwater monitoring (Day 4)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
Dec. 13-16, 2004	ISB sampling, monthly (Days 8-11)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
Dec. 22, 2004	Groundwater monitoring (Day 18)[e]	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
Jan. 10-13, 2005	ISB sampling, monthly (Days 36-39)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
Jan. 17-28, 2005[d]	Analyze current data/ process decision	NA
Jan. 31, 2005	Whey injection #4 (Day 1)	TSF-05 (NA)
Feb. 1, 2005	Groundwater monitoring (Day 2)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
Feb. 3, 2005	Groundwater monitoring (Day 4)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
Feb. 7-10, 2005	ISB sampling, quarterly (Days 8-11)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
Feb. 21, 2005	Groundwater monitoring (Day 22)	TSF-05A, TSF-05B, TAN-31 (AED Analysis Set) TAN-25 (AED Analysis Set, MP)
Mar. 7-10, 2005	ISB sampling, monthly (Days 36-39)	TSF-05A, TSF-05B, TAN-31, TAN-26 (AED Analysis Set, ^{3}H, GS) TAN-25 (AED Analysis Set, MP, ^{90}Sr, ^{3}H, GS)
Mar. 14-Apr. 8, 2005[f]	Analyze current data/ process decision	NA
Apr. 11, 2005[g]	Prepare report	NA

a. The analyte set key is provided in Table B-2.

b. Sampling postponed 1 day due to Memorial Day Holiday.

c. Sampling postponed 1 day due to Labor Day Holiday.

d. The optimization may be terminated upon determination that sufficient data have been obtained.

e. Samples collected on Day 18 due to INEEL Christmas work curtailment.

f. The optimization may be extended to gather additional data.

g. In the event that the optimization is terminated before or extended beyond four AED injections, preparation of the report will commence upon analysis of all AED optimization data.

Table B-2. Key for analyte sets shown in Table B-1.

Analyte Set Code	Analytes
AED Analysis Set	Lactate and electron donor degradation products (propionate, butyrate, acetate, lactate), chemical oxygen demand, VOCs (PCE, TCE, cis-DCE, trans-DCE, VC), and dissolved gases (ethene/ethane/methane), redox indicators (sulfate, iron, pH, ORP)
MP	Microbial parameters (DNA)
^{90}Sr	Sr-90
^{3}H	Tritium
GS	Gamma screen
NA	No samples collected